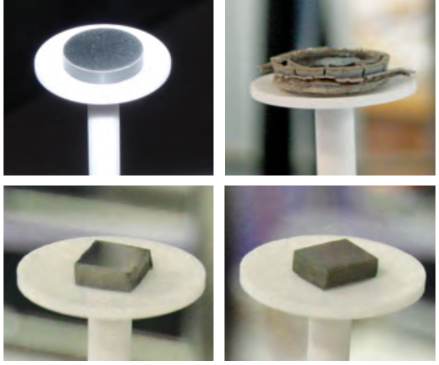
spotlights



(Upper row) Zirconium alloy test sample before (left) and after (right) being damaged by temperature and steam conditions typical of a loss-of-coolant accident in a nuclear reactor. (Lower row) PM2000 metal before (left) and after (right) being subjected to the same conditions.

CREDIT: ANDREW NELSON/LANL

Safer Nuclear Power

The worst nuclear accident in U.S. history took place in 1979 at the Three Mile Island (TMI) nuclear generating station in Pennsylvania. Radioactive gases were released, but the quantities were low enough that, evidently, no one was hurt. The more recent Fukushima disaster was similar to the TMI event, in that each was a loss-of-coolant accident (LOCA), which is essentially a plumbing problem: plant operators are unable to pump cool water through the reactor core, causing the core to get hotter and hotter. Even though any normal failure incident (faulty pump, earthquake, etc.) that could lead to a loss of coolant triggers a scram, in which control rods are inserted to halt the nuclear fission reactions, radioactive elements continue to generate heat inside the reactor as they decay.

That by itself wouldn't be so bad—plant operators could just wait out the radioactive decay, after which the temperature would start to drop—if there weren't a second heat source inside the reactor. As the core temperature rises above a particular threshold, the thin tubes that encase each of the reactor's tens of thousands of fuel rods begin to oxidize, generating additional heat. Without cooling water, that additional heat continues to escalate temperatures, melting core components and eventually leading to containment failure and serious public health risk. Now, Los Alamos scientists, in collaboration with scientists from the Idaho and Oak Ridge national laboratories, are investigating a way to prevent that second heat source from kicking in.

The tube used to isolate the radioactive fuel from the water coolant, known as cladding, is usually made from a zirconium alloy chosen for its transparency to neutrons, because neutrons sustain the reactor's fission reactions under normal operating conditions. But when temperatures rise above 750°C under LOCA conditions, the zirconium undergoes a chemical reaction with the water (in the form of steam) that fills the reactor. The oxygen in the water reacts with zirconium metal to form zirconium oxide, which makes the cladding degrade and flake away. If this reaction continues, the highly radioactive fission products that were safely contained inside the cladding become free to mix with the water, greatly increasing the danger in the event of a loss of containment. Meanwhile, the hydrogen builds up pressure that could ultimately cause an explosion and breach of containment, as happened following the earthquake and tsunami at Fukushima. And because the reaction generates heat, once it begins, the reactor temperature will climb higher.

To prevent the reaction from starting in the first place, Los Alamos materials scientists Andrew Nelson and Stuart Maloy are using a novel experimentation platform to test zirconium and other cladding materials in the presence of steam at extremely high temperatures. Their experimental setup combines thermogravimetric analysis, which monitors the weight change as zirconium becomes zirconium oxide, with evolved gas analysis, which monitors the production of hydrogen.

They discovered, for example, that conventional stainless steel won't begin to oxidize until the temperature rises another 150° or so beyond the oxidation temperature for the zirconium alloy, up to 850–900°C. Therefore, if stainless steel were used to replace the zirconium alloy, it could buy plant operators more time to get cooling water into the reactor before it reaches the oxidation temperature. But without cooling water, the reactor will still reach that temperature following a typical LOCA.

"The explosion at Fukushima might have happened a few hours later with conventional stainless steel cladding," Nelson says, "but it still would have happened."

However, when Nelson and Maloy tested a commercial variety of stainless steel enriched with aluminum, known as PM2000, they found that the oxidation reaction didn't generate significant heat up to 1200°C—at least 200° hotter than a reactor undergoing a TMI- or Fukushima-type LOCA should get from radioactive decay heat alone. Furthermore, the oxide formed by the reaction was protective; it did not flake off. This could be game-changing: if PM2000 cladding is used, LOCAs like these should no longer lead to explosion or meltdown, and radioactive material will not get out. More research is needed, however, to test the corrosion and radiation resistance of PM2000 under long-term reactor use. And procedures need to be developed for producing thin tubes and making sound welds from the alloy.

Will this discovery improve nuclear power safety under accident conditions? "It will certainly be much safer," answers Nelson, who argues that nothing can make it 100 percent safe. "PM2000 cladding won't save you if the reactor is hit by a meteor." Yet, cosmic collisions aside, commercial adoption of cladding made from PM2000 or a similar alloy may depend upon an economic question: will nuclear fuel vendors be able to recover the R&D costs of developing these new fuel rods? Nelson, who collaborates on this issue with the two largest U.S. vendors, General Electric and Westinghouse, is hopeful that the answer is yes and that safer nuclear power—using existing power plants—really is on its way. Because PM2000 is also likely to withstand normal operating conditions better than zirconium alloy, power plants may be able to operate their reactors for longer periods of time between refueling and maintenance shutdowns. And more time online is more time earning revenue.

—Craig Tyler

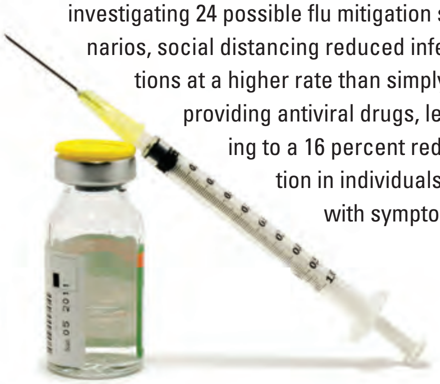
Preventing a Pandemic

The H1N1 influenza outbreak during 2009 was the first new flu strain with global reach in 40 years, and its initial virulence alarmed public health officials. As the pathogen spread from Mexico to the U.S. in early spring, the Department of Homeland Security hired a team from Los Alamos, Argonne, and Sandia national laboratories to simulate the pandemic in the United States.

Influenza outbreaks are a combination of unpredictable human and virus behavior, so they are fraught with uncertainty. The outcome of H1N1 was less severe than past flu pandemics, but Los Alamos-led research now explains how much worse it could have been. Understanding how scenarios based on the potential range of uncertainties could unfold will help federal and local agencies stockpile vaccines and antiviral drugs to plan for future worst-case events.

The Critical Infrastructure Protection and Decision Support Systems (CIPDSS) research team used infrastructure models combined with a general infectious disease model to study an additional element of the pandemic—how absence from work during an outbreak affects the economy. Specifically, the team's simulation involved a public health strategy called "social distancing," in which people who feel well avoid work and school.

In a recent publication of the 2009 study investigating 24 possible flu mitigation scenarios, social distancing reduced infections at a higher rate than simply providing antiviral drugs, leading to a 16 percent reduction in individuals with symptoms.



However, that mitigation strategy was costly. There was a 50 percent decrease in gross domestic product over the course of the epidemic due to worker absences.

The CIPDSS team, including Rene LeClaire, Dennis Powell, Leslie Moore, Lori Dauelsberg, and others, also found that keeping kids from school during the modeled pandemic didn't entirely squelch the disease but did delay it. That technique could give researchers several months to develop or accumulate vaccines and antiviral drugs. "We're just trying to buy time through hand washing and social distancing while we're making the vaccine," said Jeanne Fair, infectious disease expert at Los Alamos and lead analyst for the project.

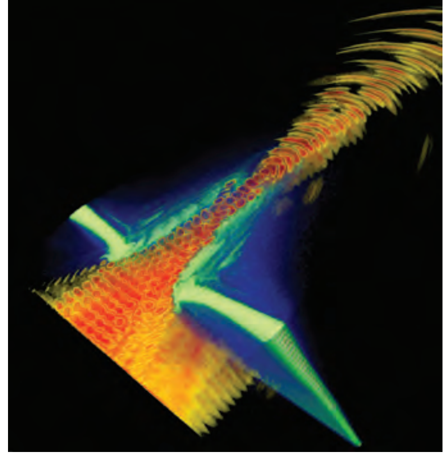
While H1N1 wasn't as devastating as public health officials feared, Fair says the analysis demonstrates the need to remain vigilant against future contagions. The worst-case scenario in the study could have four times more flu-caused fatalities in the United States than the estimated 675,000 (and perhaps 50 million worldwide) from the 1918 outbreak, which is the most severe flu pandemic on record.

—Sarah Keller

Laser Clarity

More than 50 years ago, scientists predicted that a laser could generate ions by driving the electrons in plasma to near the speed of light. Plasma typically reflects laser light, but when a strong laser accelerates electrons in the charged gas, plasma can become transparent. During this phenomenon called relativistic transparency, the laser's energy is transferred to electrons in the plasma, which in turn energizes ions. Until recently, researchers could only test the fundamental physics of relativistic transparency in computer simulations.

In research published last summer, plasma physicists at Los Alamos, along with collaborators in Germany and the United Kingdom, observed the dynamics of relativistic transparency for the first time. To do so, they directed the Laboratory's 200 trillion-watt peak power short-pulse TRIDENT laser at 10- to 100-nanometer thick carbon foils to generate an electron-rich, transparent plasma. The team's new understanding of the relativistic transparency can be applied to developing laser-driven particles accelerators, x-ray sources, and ions for cancer treatment.



In this research simulation of relativistic transparency, Los Alamos's Trident laser (orange) penetrates a 100-nanometer-thick carbon nanofoil (green). This generates a plasma, which typically reflects laser light like a mirror. Shown here, however, the strong laser drives the plasma electrons to near the speed of light, making the plasma transparent to the laser. Los Alamos plasma physicists have observed the dynamics of this for the first time.

CREDIT: DANIEL JUNG AND HUI-CHUN WU/LANL

Relativistic transparency happens in a tenth of a picosecond, about the time it takes light to travel 1/30th of a millimeter. Previous studies had much lower time resolution, which limited how well researchers could understand the process. The new results will help advance work to precisely control the shape and timing of laser pulses, which is necessary for developing laser-driven particle accelerators that are smaller and less expensive than conventional accelerators.

The team found close agreement between current laser-plasma interaction models and their experiments, which confirms what Los Alamos scientists have long suspected—that directing a short-pulse laser at a very thin carbon foil target will make the foil transparent to the laser. "It validates the simulation code that researchers have been using for some time," said Sasi Palaniyappan of the Los Alamos plasma physics group. "At the same time it also tells us that we're doing an experiment that's as close as possible to simulation."

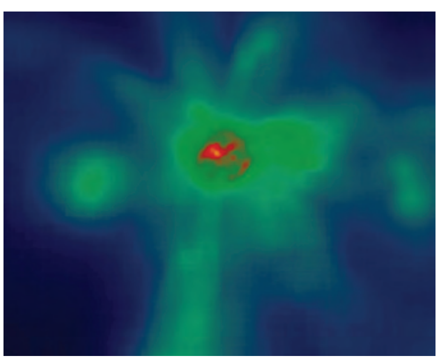
Researchers are investigating energetic ions, like those created during relativistic transparency by compact, high-powered lasers, as alternatives to traditional radiation therapy for cancer. The plasma physics team at Los Alamos is currently using TRIDENT for basic physics research to explore how to achieve the ion properties required for cancer treatment using laser-based ion acceleration. ❖ LDRD

—Sarah Keller

Great Balls of Fire

The largest black holes in the universe, known as supermassive black holes (SMBHs), are found at the centers of galaxies and can have billions of times the mass of the Sun (billions of solar masses). But black holes are created by the deaths of massive stars, and the largest known black hole birth weight is only a little over 20 solar masses. Astronomers presumed that although black holes were born small, they grew more massive over time by pulling in nearby gas. As the reasoning went, in a universe 14 billion years old, supermassive holes had lots of time to become supermassive.

However, telescopic observations, particularly in the last decade, have cast doubt on that reasoning. Quasars, distant light sources produced by hot gas flowing onto SMBHs, have now been detected at such great distances that their observed light began its journey to Earth when the universe was less than a billion years old. And the SMBHs at the heart of these quasars were already billions (10^9) of solar masses at that time. The most distant known quasar is powered by a two-billion solar mass SMBH seen when the universe was only six percent of its present age. How could stellar-mass black holes have grown to become supermassive in so little time? Black hole growth rates are limited because when they grow too quickly, the gas near the hole becomes so bright that it pushes the surrounding gas away, reducing the hungry hole's food supply.



In this simulation, a black hole that was just formed by the collapse of a supermassive star is surrounded by a distribution of gas (color indicates density). Because the black hole (located at the center but too small to see) grows by consuming the available gas, simulations like this one help determine how quickly the black hole can grow. The progenitor of this black hole, which contained up to a hundred thousand suns' worth of mass in a single star, could only have formed in the very early universe.

CREDIT: JARRETT JOHNSON/LANL

Los Alamos astrophysicist Jarrett Johnson thinks the first SMBHs in the universe had a head start. Supermassive holes, he claims, begin with supermassive stars (SMSs)—hypothetical objects containing up to about a million (10^6) solar masses in a single star. Normally, stars can't become supermassive because the gas clouds from which they form become clumpy as they collapse, fragmenting the cloud into many smaller stars. The gravitational collapse of a large gas cloud, therefore, results in a cluster of stars, typically less than one solar mass, with perhaps a few exceeding 100 solar masses—well short of the supermassive.

But things were different in the universe's first billion years, Johnson says. "In order for gas clouds to fragment into many stars, you need atoms and molecules to radiate away the heat from the collapse, forming cooler pockets. But sometimes these atoms and molecules just weren't there." Indeed, without sufficient cooling, higher temperatures meant higher pressures, inhibiting the collapse of gas into stars. And elements heavier than helium—those capable of providing cooling—were rare back then because they are only synthesized inside stars, and few stars yet existed. Thus with only two elements available, hydrogen and helium, there weren't many ways to radiate heat away from a gas cloud. And although molecules, including H_2, can cool regions within a larger cloud, such molecules could be dissociated into separate atoms in the presence of sufficient radiation. Without any way to cool distinct regions within the cloud, the whole thing could collapse under gravity's relentless force into a single, supermassive star. And when an SMS dies, less than a million years after its birth, its core forms a black hole that consumes most of the star, resulting in an instant 10^5 or 10^6 solar mass black hole.

Most astronomers have found this scenario unlikely, doubting that large regions could be flooded with enough molecule-dissociating radiation, sustained long enough to grow SMSs. But Johnson's research says otherwise. Together with collaborators from the Max Planck Institute in Germany, he performed large-scale cosmological simulations to search for the emergence of star-forming gas clouds embedded in a bath of molecule-dissociating radiation. Such conditions, he discovered, occur much more often than previously expected. In addition, he and Los Alamos colleagues Dan Whalen, Chris Fryer, and Hui Li modeled the conditions under which an SMS would form and found growth rates that similarly exceeded expectations: Once the collapse progresses to the point where the star "turns on," it continues to grow from rapidly infalling gas. The rate of infall is limited by the bright starlight that tends to push the gas away, but nonetheless, he found that accumulations up to about 10^6 solar masses are possible by the time the star dies and becomes a black hole.

Johnson is gratified with his results. "The emergence of billion-solar-mass black holes in the first billion years has been a major mystery in astrophysics," he says. "I think we finally have a plausible explanation." Johnson's work shows the validity of SMS formation—perhaps even widespread SMS formation—in the early universe, providing a much-needed way to kick-start the growth of SMBHs. Better still, if he's right, then ancient SMSs should be observable for the first time with the James Webb Space Telescope, Hubble's successor, which is planned for launch in 2018. ❖ LDRD

—Craig Tyler